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Ecological characteristics of subterranean termites in Mamar agroforestry, West Amarasi, Timor Island, Indonesia

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Abstract. *Kusumawardhani DT, Kapitan OB, Nufus MR. 2025. Ecological characteristics of subterranean termites in Mamar agroforestry, West Amarasi, Timor Island, Indonesia. Biodiversitas 26: 5857-5869.* Mamar, a traditional agroforestry system on Timor Island, Indonesia, is overgrown with various local and introduced forest trees, and fodder crops, which influence the organic matter that needs to be decomposed. Subterranean termites act as decomposers, although the specific species remains unidentified. This study, conducted in Soba Village, West Amarasi Sub-district, Kupang District, East Nusa Tenggara, Indonesia, aimed to identify termite species in Mamar, analyze their environmental conditions, and assess the soil characteristics within and around their nests. The study utilized a 150x250 m sample plot across three locations, each representing different contours, altitudes, and soil colors of Mamar. Two successfully identified species of subterranean termites from eight nest, *Macrotermes gilvus* NC034110.1 and *Nasutitermes matangensis* MTR C-004. Environmental parameters (temperature, humidity, and light intensity) were monitored over three months (March-July) showing ranges of 23.03-28.65°C, 65.41-84.87%, and 594.19-2529.9 lux, respectively. These conditions were generally suitable for termite activity, although humidity levels occasionally dropped below optimal. Soil characteristics focused on moisture content, soil acidity (pH value), C-organic, total nitrogen, organic matter, and texture of the three fractions. Nest soils exhibited higher pH, carbon, nitrogen, and organic content compared to surrounding soils. Moisture content varied by texture, higher in clay, lower in loam and clay loam. As decomposers and soil engineers, both termites can contribute to improving the inceptisol soil properties of Mamar by enriching organic matter. The greater the number of plants in Mamar, the more it influences termite activity, especially *M. gilvus*, which needs raw materials to make fungus comb in their nests. Meanwhile, the island's dry climate and low rainfall force termites to adapt to suboptimal moisture conditions, even within their own nests.

Keywords: *Macrotermes gilvus*, multinomial regression analysis, *Nasutitermes matangensis*, soil characteristic, traditional agroforestry

INTRODUCTION

East Nusa Tenggara, especially Timor Island, Indonesia, is unique in its climatic conditions. This uniqueness is specifically referred to as the semiarid tropical climate, characterized by a summer season that is longer than the rainy season. In response to the semiarid tropical climate, the people of Timor Island have developed a traditional agroforestry system called Mamar on dry land to meet their daily needs. Mamar utilization activities take place in the "Kopa" zone, which consists of forest plants, and a development zone that can be utilized for annual crops and livestock (Suek et al. 2018; Basri et al. 2021; Moata et al. 2022). Mamar can also be interpreted as an artificial oasis on Timor Island (Lewoleba et al. 2023).

In general, Mamar is overgrown by coconuts (*Cocos nucifera*), areca nuts (*Areca catechu*), betel (*Piper betle*), banana (*Musa acuminata*), fruit plants, other woody plants (various local and introduced forest trees), and fodder crops (i.e., grass, *Leucaena* spp., and *Sesbania* spp.) (Suek et al. 2018), which are integrated for water conservation, sustainable economic, and social-cultural utilization within the Kopa zone. Njurumana (2009) details that there are 112 species of plants and herbs found in Mamar with multi-layered canopy. The condition of Mamar is significantly different from the typical agroforestry system, which has a composition of 88% overgrown with non-timber forest products and 12% woody plants. Although woody plants make up only 12% of the total vegetation cover, they consist of many species that dominate the upper canopy of Mamar system. This condition also affects the amount of organic matter that Mamar produces, which needs to be decomposed so that nutrients can be replenished in the soil, making them available for plant uptake (Sudomo et al. 2023). One of the insects that act as decomposers is the subterranean termite.

Subterranean termites are the most common tropical decomposers in forest ecosystems, agricultural land, plantations, and urban and settlements areas (Kuswanto et al. 2015; Nandika et al. 2020a). Rahman et al. (2022) and Manoppo et al. (2024) stated that the diversity of woody plant species, temperature, and humidity typical of tropical climates and organic-rich soils provide ideal termite habitats. Nowadays, subterranean termites can be easily found in many land use areas and at various altitudes. Godfrey et al. (2017) and Felicitas et al. (2018) found subterranean termites in cocoa and banana agroforestry systems in tropical regions with varying levels of land cover. Zulkaidah et al. (2025) reported that termites have also been found in agroforestry at an altitude of 600-1000 meters above sea level (m asl) in Lore Lindu. Termites as soil engineers, play a vital role in enhancing soil fertility and hold promise for application in the pursuit of sustainable agriculture, as well as agroforestry (Febriani et al. 2025). Although several studies on termites in agroforestry have been reported, the ecology of termites and the effects of termite activity on soil in agroforestry have not been widely reported.

Nandika et al. (2020b) and Pradipto and Afif (2020) noted the presence of termites on Timor Island and reported termite attacks on buildings, although the species involved were not identified. Local residents also frequently encounter termites within Mamar areas. Despite these observations, neither the species nor their ecological roles in Mamar or surrounding agricultural land and settlements have been documented (Kusumawardhani and Almulqu 2024). Basri et al. (2020) reported that the Mamar in Soba Village lies very close to residential zones, and preliminary surveys in the same area show that Mamar use overlaps with settlement boundaries, an unique characteristic integration typical of West Amarasi landscapes. Without knowing which subterranean termite species occur there, it is difficult to understand the benefits they provide or the potential damage they may cause. Such information is essential for developing science-based management strategies in semiarid environments. Given these considerations, this study aimed to identify subterranean termite species, describe their ecological characteristics, and assess soil chemical properties influenced by termite activity in Mamar and nearby agricultural land on Timor Island. The study offers an initial ecological description rather than quantitative estimates of termite abundance or diversity.

MATERIALS AND METHODS

Materials

The tools used in this study include specimen collection bottles, soil drills, crowbars, ziplock plastic, roll meters, which are used to observe nests, take soil samples, collect termite specimens found, and observe the termites; Garmin eTrex 10 Global Positioning System (GPS) tools, light meters, and hygrometers to take complementary data needed in this study. The materials used in this study consisted of 70% alcohol, distilled water, aluminum foil, and soldier caste termite specimens.

Time and locations

The study was conducted from March to July 2024 at Mamar and on agricultural land adjacent to Mamar in two of hamlet area in Soba Village, West Amarasi Sub-district, Kupang District, East Nusa Tenggara, Indonesia. Termite specimens were identified in the laboratory of the Politeknik Pertanian Negeri Kupang, Kupang District. In addition, the collected soil characteristics were analyzed at the Indonesian Center for Biodiversity and Biotechnology (ICBB) in Bogor, West Java, Indonesia.

Procedures

Termite specimen collection

The termite nests were searched in five continuous observation plots, measuring 150 m by 250 m in a rectangular shape, at three locations representing different contours, altitudes, and soil colors. These locations were 350 m asl, 400 m asl, and 450 m asl, and the soil colors were white, yellow, and brown, respectively. Each observation plot was conducted once at each contour, elevation, and soil color. The determination of these three altitudes was carried out to see the distribution of termite nests contained in the Mamar and agricultural land beside the Mamar of Soba village, where they were found at an altitude of 348-462 m asl. Contour and boundary maps were needed to determine the starting point for setting up the observation plots. When termite nests were found, whether epigeal, arboreal, or hypogeal, within the observation area, their locations were immediately recorded using a Garmin eTrex 10 GPS device. Soldier caste termite specimens found at each nest and location were picked by using bird feathers and placed into collection bottles treated with 70% alcohol separately. Each bottle was labeled with the area where the termites were collected.

Termite species identification

Each soldier caste termite specimen from each sample site was identified using the termite species identification key by Ahmad (1958), Tho (1992), Robert et al. (2007), and Syaukani and Thompson (2011). DNA barcoding was not performed in this study. Morphological and morphometric observations were also made on termite specimens from each sample site. Morphological observations were made on all parts of the termite body, including shape, color, and other characteristics found on the termite body parts. Morphometric data were obtained by measuring each termite specimen three times from the same collection bottle. The head of the soldier caste was measured (Takematsu and Vongkaluang 2012), namely: head length without mandible (HLWM), head width at the base of the mandible (HWBM), maximum head width (MHW), left mandible length (LML), pronotum length (PL), maximum pronotum width (MPW), postmentum length (LPos), postmentum width (WPos), and number of antenna segments. Measurements of the external anatomical parts of the soldier termite head can be seen in Figure 1. Observations and photographs of the specimens were made using a digital microscope.

Measurement of temperature, humidity, and light intensity

Temperature, humidity, and light intensity were measured using a ®UNI-T UT333 Hygrometer and a ®Kuber AS803 Digital Lux Meter to support this study. Measurements were taken only once a day, beside each nest found in the study location: in the morning (8:00 AM), afternoon (12:00 PM), and evening (4:00 PM) (Arinana et al. 2016). The hygrometer and light meter are calibrated before each data collection. Data collection was carried out for 5 minutes before the data was read.

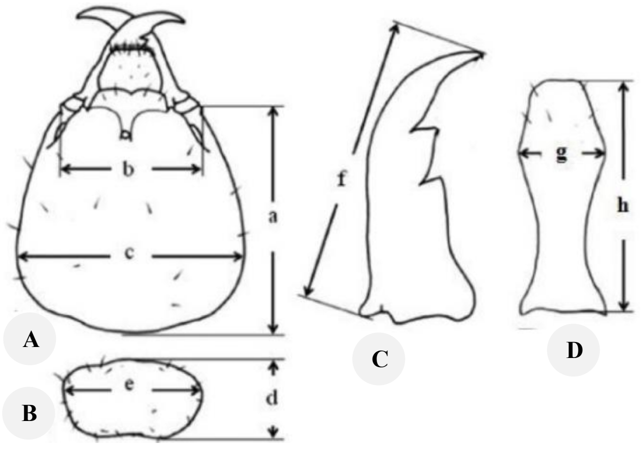

Figure 1. Termite measurements for morphometric data. A: Head, B: Pronotum, C: Left mandible, D: Postmentum. a: HLWM, b: HWBM, c: ML, d: PP, e: LMP, f: PMK, g: WPos, h: LPos (Takematsu and Vongkaluang 2012)

Soil characteristics

To support this, soil samples were taken at three locations: the subterranean termite nest, 50 cm away from it, and 100 cm away from it, at a depth of 10-20 cm below the soil surface. Each soil sample was taken from four cardinal directions from the nest. Thus, there were four test repetitions in each location. These distances were chosen to observe soil properties affected by termite activities. The tests conducted included soil physical properties, such as moisture content and texture of three fractions by using the gravimetric method (SNI 6371:2015); as well as chemistry properties, which consisted of C-organic content by using the spectrophotometric method (Bahadori and Tofighi 2016), N-total content by using the Kjeldahl method (FAO 2021), and soil acidity measurements were carried out using H_2O as an extractor solution (1:1 soil: H_2O ratio) using a glass electrode of a pH meter (Rinaldy et al. 2023).

Data analysis

Environmental data and measurements of subterranean termite size were processed using Microsoft Excel 2021. Morphometric variables were summarized descriptively to determine mean values and ranges for each specimen. ImageJ software was used to analyze the relationship between termite morphology and morphometry. Multinomial regression was applied to evaluate how a multi-category response variable relates to one or more categorical or continuous predictors (Farghali et al. 2021; Lay-Raby et al. 2021). This analysis was conducted only for nest codes 2, 4, 7, and 8. Vegetation surrounding each nest was classified into grasses (Category 1), shrubs (Category 2), and trees (Category 3). The significance level was set at α: 0.05, with significance markers defined as p <0.05 (*), p<0.01 (**), and p<0.001 (***). The model was fitted in RStudio using the "multinom" function, with vegetation type as the predictor and nest category as the response variable. Model performance was assessed using AIC, Standard Errors (SE), and p-values for all predictors. Only nests 2, 4, 7, and 8 met the minimum requirements for multinomial modeling because they contained complete vegetation data (grasses, shrubs, and/or trees) and full soil measurements (C-organic, total nitrogen, organic matter, pH, moisture, and C/N ratio). Multinomial regression requires each response category to have more than one observation and adequate variability in predictor values to ensure stable parameter estimation. Other nests were excluded due to missing vegetation categories or zero variance in predictors, which can lead to quasi-complete separation or prevent model convergence. Thus, nests 2, 4, 7, and 8 provided the most statistically reliable dataset for examining the relationship between vegetation structure and soil chemical properties. Pearson correlation analysis was conducted to evaluate associations between soil texture components (clay, silt, sand) and nest moisture content, with the goal of identifying which soil attributes most strongly influence water-holding capacity. Correlation coefficients (r) and p-values were calculated. Because only a small number of termite mounds had complete data, all statistical analyses were exploratory. Both regression and correlation analyses were used to highlight possible relationships rather than to draw population-level conclusions. Results were interpreted as descriptive patterns rather than confirmatory statistical tests. Cross-validation and confidence intervals were not applied due to the small sample size and the non-parametric nature of the dataset. The multinomial regression was therefore used mainly to visualize relationships among vegetation categories and soil variables, and the limited sample size (n: 8) and incomplete category representation mean that key assumptions of multinomial logistic regression (independence, proportional odds, adequate sample size) were not fully satisfied. Consequently, model outputs were interpreted qualitatively. Pearson correlations were used to explore linear associations among soil variables, and correlations between total nitrogen and organic carbon were interpreted cautiously because their shared calculation components can produce mathematical, rather than biological, relationships. Corresponding p-values and sample sizes (n) were reported to evaluate the reliability of each correlation.

RESULTS AND DISCUSSION

Nest distribution

The site survey results showed that only eight termite nests were found in Mamar and on agricultural land beside Mamar, scattered randomly between coordinates 10°16'45.50"S, 123°44'2.33"E and 10°16'56.80"S, 123°43'10.23"E (Figure 2). The number of nests found can be considered small. Heriza et al. (2024) stated that the number of nests in tropical regions varies greatly.

The termite nests were found scattered throughout the Mamar with six nests, and around the agricultural land with two nests. Each nest is under the shade and around different plants (Table 1). The surface of the termite nest was only 3-18% covered with litter and plants. There are tree species such as *Tectona grandis, Tamarindus indica, Ceiba pentandra,* and *Leucaena leucocephala*, that can grow well in the environmental conditions of East Nusa Tenggara. These plants are also characteristic of the mixed deciduous monsoon forest type (Widiyono 2008). However, further study is needed to confirm this as a distinct type of mixed deciduous monsoon forest.

Identification of subterranean termites

The results of identifying termites from the soldier caste, based on morphological characteristics of the whole body, head capsule, and mandible collected from each nest, indicate that at least two species of subterranean termites from the family Termitidae were found: *Macrotermes gilvus* and *Nasutitermes matangensis*. Heriza et al. (2021) stated that termite diversity in agroforestry is lower than in natural forests.

Macrotermes gilvus

The identification results, based on the description in the termite identification key by Robert et al. (2007), revealed that the subterranean termite species found in several nests in Mamar was *M. gilvus* (Figure 3). *Macrotermes gilvus* was found to exhibit have dimorphism characteristics with differences for major soldiers with an overall body size that is larger than minor soldiers, symmetrical mandibles extending forward shaped like a thick sickle, a head with a clear fontanel on the front of the head, a dark reddish-brown head, there is a distribution of hair on the body, a wide horse saddle-shaped pronotum, and 17 segments of antennae with the third segment longer than the second and fourth segments. These morphological characteristics are consistent with the descriptions by Ahmad (1958) and Tho (1992), confirming the species' identity as *M. gilvus*. Minor variations in body size may reflect local adaptation or environmental influence. Arinana et al. (2025) stated that major and minor soldiers exhibit differences in body size, which enables them to perform better in nest and colony protection, as each soldier has its specific tasks and roles. Additionally, the termites exhibit the following size characteristics, as shown in Table 2.

Indonesia, Malaysia, and Thailand are the three countries in Southeast Asia that serve as the central distribution hubs for *Macrotermes* (Khan and Ahmad 2018). These three countries have natural forests where environmental conditions, including temperature, humidity, and rainfall, are relatively stable, providing a natural habitat for *Macrotermes* termites. However, global climate change and habitat conditions, such as deforestation, have altered the current distribution of termites, forcing them to adapt their habits, relocate to new areas, or reduce their population numbers (Heriza et al. 2024). Termites of the genus *Macrotermes* can easily be found at various elevations 460-715 m asl (Haneda and Firmansyah 2012; Indrayani et al. 2022). *Macrotermes gilvus* has been reported to be widely distributed in Indonesia (Pratiknyo et al. 2020; Nurhadi et al. 2023; Kusumawardhani and Almulqu 2024; Arinana et al. 2025; Dirna and Wahyuningtyas 2025). The presence of *M. gilvus* in Timor Island confirms its adaptability across diverse ecological zones. It suggests a potential range extension that may be influenced by environmental pressures such as land-use change (Vermelho et al. 2024).

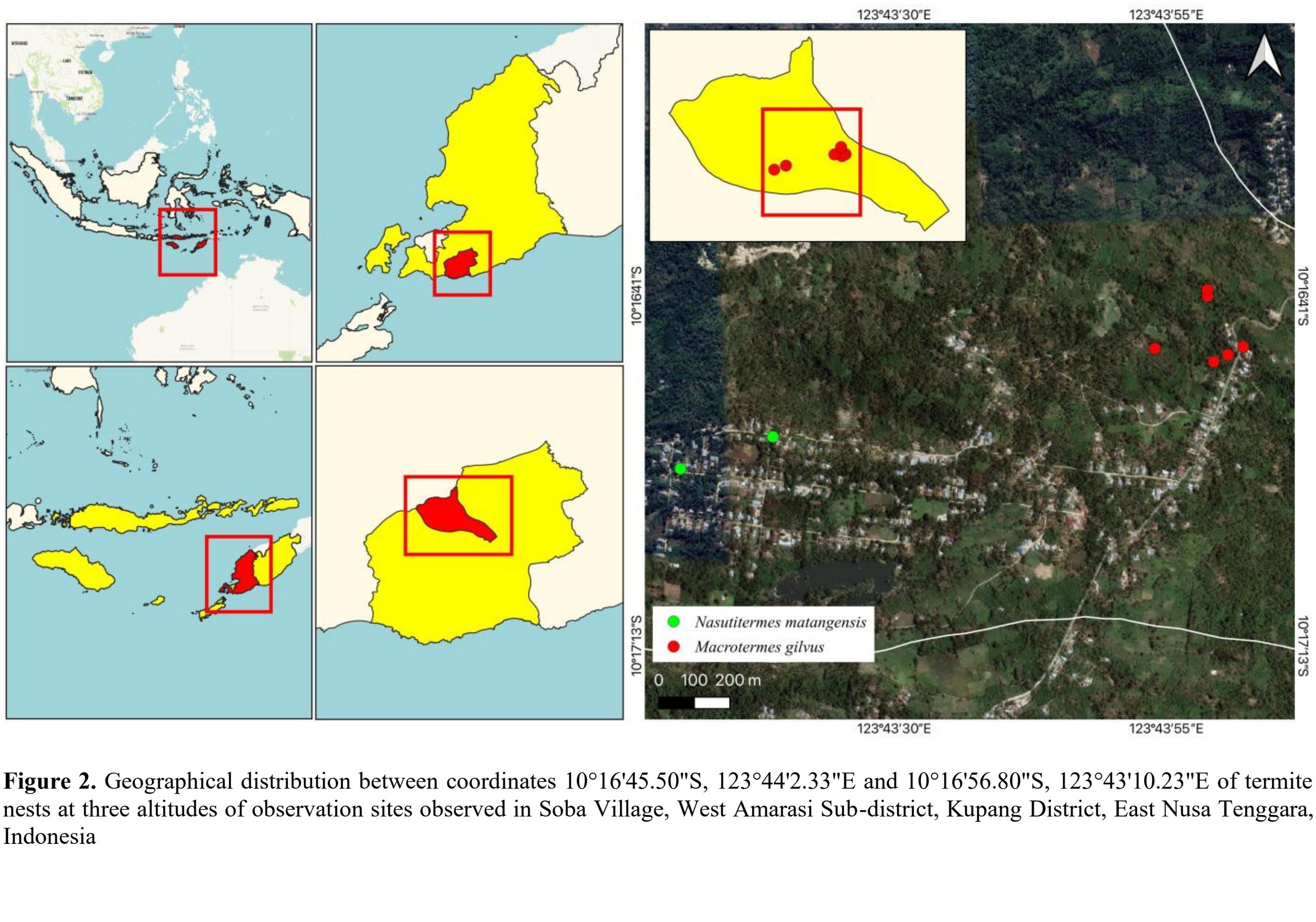

Figure 2. Geographical distribution between coordinates 10°16'45.50"S, 123°44'2.33"E and 10°16'56.80"S, 123°43'10.23"E of termite nests at three altitudes of observation sites observed in Soba Village, West Amarasi Sub-district, Kupang District, East Nusa Tenggara, Indonesia

Table 1. List of plant species included in the 20x20 m vegetation analysis plot around the termite nests found

Nest	Location	Coordinates	Number of species	Species of plants
1	Mamar	10°16'45.50"S, 123°44'2.33"E	9	1. *Ischaemum timorense* 2. *Chromolaena odorata* 3. *Gmelina arborea* 4. *Ocimum basilicum* 5. *Tamarindus indica* 6. *Aleurites moluccana* 7. *Delonix regia* 8. *Barleria prionitis* 9. *Flemingia strobilifera*
2	Mamar	10°16'46.89"S, 123°43'59.60"E	7	1. *I. timorense* 2. *C. odorata* 3. *B. prionitis* 4. *Leucaena leucocephala* 5. *T. indica* 6. *Tectona grandis* 7. *Ceiba pentandra*
3	Mamar	10°16'46.24"S, 123°44'0.91"E	6	1. *Bothriochloa pertusa* 2. *B. prionitis* 3. *Pennisetum purpurophoides* 4. *L. leucocephala* 5. *C. pentandra* 6. *Musa paradisiaca*
4	Mamar	10°16'45.67"S, 123°43'54.15"E	8	1. *B. pertusa* 2. *B. prionitis* 3. *Gliricidia sepium* 4. *G. arborea* 5. *T. grandis* 6. *C. pentandra* 7. *T. indica* 8. *Cleistanthus collinus*
5	Mamar	10°16'40.80"S, 123°43'59.03"E	8	1. *I. Timorense* 2. *C. Odorata* 3. *B. prionitis* 4. *G. sepium* 5. *Psidium guajava* 6. *G. arborea* 7. *T. Grandis* 8. *C. collinus*
6	Mamar	10°16'40.24"S, 123°43'59.01"E	5	1. *I. timorense* 2. *C. odorata* 3. *G. sepium* 4. *P. guajava* 5. *Cassia siamea*
7	Agricultural land	10°16'53.13"S, 123°43'59.01"E	8	1. *I. timorense* 2. *Morinda citrifolia* 3. *P. purpurophoides* 4. *T. grandis* 5. *Cocos nucifera* 6. *Ficus calosa* 7. *Swietenia mahagoni* 8. *Annona muricata*
8	Agricultural land	10°16'56.80"S, 123°43'10.23"E	6	1. *I. timorense* 2. *Mangifera indica* 3. *C. nucifera* 4. *Persea americana* 5. *Lannea coromandelica* 6. *L. leucocephala*

Nasutitermes matangensis

The second subterranean termite species identified using the description in the termite identification key from Robert et al. (2007) is *N. matangensis* (Figure 4). This species is found in several nests in Mamar and the surrounding community settlements. *Nasutitermes matangensis* was found to have monomorphic characteristics: a dark brown head with the color of the rostrum and antennae darker than the head capsule, several hairs on the head, and 13 antenna segments. The head capsule is round when viewed from the dorsal direction. The pronotum is paler in color than the head capsule. The abdomen is pale brown. Additionally, the termites exhibit the following size characteristics, as shown in Table 3.

Based on the characteristics of the termites observed, the results obtained are by the identification key and study conducted by Syaukani and Thompson (2011) with the identification results of *N. matangensis* having the characteristics of the dorsal view of the posterior margin of the head capsule almost straight in the middle, the dorsal line (including the rostrum) in profile is almost straight, curved downward apically, the maximum width of the head capsule is 1.37-1.50 mm. *Nasutitermes* is one of the most abundant groups of wood-eating termites in the tropics and is very diverse and heterogeneous in terms of biogeography and morphology, but the existence of species of this genus *Nasutitermes* is not well described; in other words, the phylogenetic status of these groups is still unclear, so that they are often misidentified (Boulogne et al. 2017; Ismail et al. 2020).

Nasutitermes matangensis has been reported to be found at various elevations (<100-1400 m asl) in Indonesia (Syaukani and Thompson 2011; Subekti et al. 2018; Novita et al. 2020; Prastyaningsih et al. 2020). *Nasutitermes matangensis* is commonly found on slopes of 40.09-65.37% (Subekti and Milanio 2023). Upon direct observation, *N. matangensis* was often found on the soil surface, under the bark of the roots, trunk, and branches, but not in the upper third of the tree. The presence of *N. matangensis* in this location at lower altitudes and moderate slopes aligns with previously reported habitats, supporting its adaptability across ecological gradients in Indonesia.

Weather characteristics

The primary factors influencing a termite colony's activities, growth, and behavior are temperature and humidity (Ferreira et al. 2019; Arinana et al. 2022). Termites build nests to establish a suitable microclimate for survival (Arinana et al. 2016). Nandika et al. (2015) reported that termites thrive at a temperature between 25-36ºC, while Nurhadi et al. (2023) found an optimal range of 23-37.6ºC. Additionally, termites require humidity levels between 75% and 90% for survival. The temperature and humidity conditions observed at the study site near the termite nests in Mamar, which were measured over three months, were found to be within a suitable range, as shown in Table 4. These results are consistent with the findings in the literature, suggesting that the environmental conditions at the study site are favorable for termite activity.

The lowest measured temperature was 23.03ºC, and the highest was 28.65ºC; humidity is often below the level suitable for termites to live, ranging from 65.41% to 84.87%. The lowest humidity was observed in the afternoon, especially in July (65.41%), and the highest in the morning, especially in June (84.87%). Arinana et al. (2025) also reported that the humidity measured in Jakarta Province is often inappropriate, ranging from 55% to 95%. Despite slight deviations in afternoon humidity, termite activity remained stable, which aligns with previous studies suggesting behavioral mechanisms, such as tunnel building, help regulate microclimatic conditions inside the nest. These findings reinforce the idea that *Macrotermes* species are capable of surviving in environments with fluctuating humidity by isolating themselves under soil tunnels, which creates optimal air humidity, as reported by Richardson and Sun (2023).

Table 2. Size of *Macrotermes gilvus* soldier's caste collected from the entire nest: major (n: 100) and minor (n: 100)

Part of *Macrotermes gilvus*	Major soldier		Minor soldier	
	Range (mm)	Average (mm)±SD	Range (mm)	Average (mm)±SD
Whole body length	7.69-11.54	8.98±0.94	3.93-7.37	5.10±1.12
Head length without mandibles	2.69-3.55	3.01±0.26	1.41-2.41	1.72±0.32
Width of head	1.93-2.75	2.22±0.28	0.84-1.79	1.17±0.30
Left mandible length	1.24-2.29	1.47±0.24	0.78-1.50	0.99±0.22
Pronotum length	0.86-1.33	1.05±0.11	0.28-0.71	0.57±0.15
Pronotum width	1.66-2.41	1.91±0.25	0.58-1.24	0.96±0.24

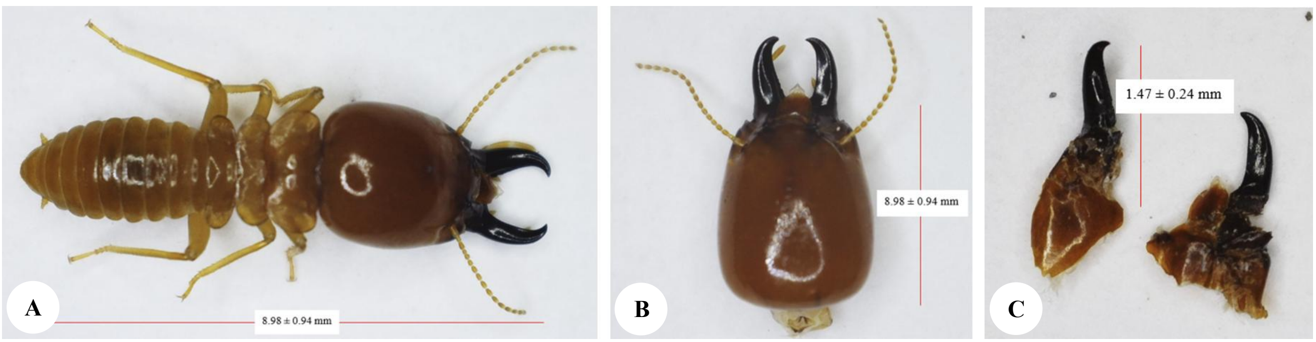

Figure 3. Morphological characters of the major soldier caste of *Macrotermes gilvus*. A: Whole body, B: Head capsule, C: Mandibles

Figure 4. Morphological characters of *Nasutitermes matangensis* soldier caste. A: Whole body, B: Head capsule with nasus

Table 3. Caste size of *Nasutitermes matangensis* soldier's caste collected from the entire nest (n: 63)

Part of *Nasutitermes matangensis*	Range (mm)	Average (mm)±SD
Whole body length	2.58-3.81	2.97±0.39
Head length without mandibles	0.86-1.77	1.10±0.25
Width of head	0.53-0.82	0.63±0.08
Pronotum length	0.16-0.27	0.20±0.03
Pronotum width	0.29-0.48	0.37±0.06

The measured light intensity was relatively high in July. Arinana et al. (2016) reported that light intensity strongly correlates with temperature and humidity. The light intensity influences fluctuations in temperature and humidity in the area. Sunlight produces radiation, increasing the Earth's surface energy, which in turn causes variations in temperature and humidity, higher sunlight intensity results in higher temperatures and lower humidity in the studied area.

Soil characteristic

General soil characteristics

Soil fauna plays a crucial role in facilitating the decomposition of organic matter in ecosystems and contributing to the soil fertility in which they reside. Soils under mixed cropping systems provide the best quality compared to those under forest and cropping systems (Moata and Takalapeta 2021). Subterranean termites *M. gilvus* and *N. matangensis*, which are classified as macrofauna, have significantly influenced changes in soil physical structure and nutrient dynamics in an ecosystem. They also maintain and improve the physical and chemical properties of the soil, which are necessary for stability and fertility (Govorushko 2018). Understanding the ecological role of termites requires examining the physical characteristics of the soil they inhabit and modify.

Soil characteristics in and around the nest need to be examined for comparison (Table 5). As Robert et al. (2007) stated, subterranean termites play an active role in ecosystems by decomposing organic matter, participating in weathering processes, regulating soil properties and hydraulics, influencing soil nutrient and chemical cycles, and affecting vegetation growth and diversity. Termites, as soil engineers in this study, appear capable of modifying the characteristics of soil; however, in this study there is no significant difference between the soil from termite nests and the soil surrounding them.

Soil criteria at the study site are clay, loam, and clay loam. According to Rompon and Almulqu (2018), the soil types in the Soba village area are eutric cambisol, ustic cambisol, or inceptisol soil types. The texture of inceptisol soils is predominantly clayey, with a high clay content (35-78%), but some are fine loamy with a lower clay content (18-35%) (Damanik et al. 2010). The clay content in termite nests ranges from 26-56%, which is lower than that around the nest, at 27-68%. According to Mujinya et al. (2013), termite nests have a texture class ranging from clay to very clayey on the mound and inside the nest, and a clayey texture class on the surrounding soil.

Teutscherová et al. (2022) reported that in various land uses such as primary forest, secondary forest, cocoa agroforestry, and maize cropland, agroforestry does indeed have lower soil chemical properties compared to other land uses, but is significantly aided by the presence of termites as decomposers that increase organic carbon in the soil. These statements align with our study on Mamar as a traditional agroforestry system, which incorporates a variety of plant species. Termite activity decomposes plant residues and alters soil characteristics within the agroforestry system. Study conducted by Kaiser et al. (2017) revealed that changes in soil physicochemical properties and nutrients due to termite activity in traditional African agricultural systems occur more frequently during the dry season than during the rainy season. Specifically, wood-eating termites, such as *Nasutitermes* and *Odontotermes*, have a lesser impact than fungus-growing termites, like *Macrotermes*. Thus, the semiarid climate can be advantageous for termite activity in Mamar, promoting decomposition and improving the physical and chemical properties of the soil.

Table 4. Temperature, humidity, and light intensity measurements at three key times during three months of direct field observations

Month	Time	Average temperature (^oC)±SD	Average humidity (%)±SD	Average light intensity (lux) ±SD
May	08.00	25.61±1.46	80.11±11.56	594.19±694.93
	12.00	28.65±0.79	70.50±4.99	1065.77±410.92
	16.00	27.43±1.19	73.84±5.22	605.71±299.70
June	08.00	23.56±1.02	84.87±4.30	623.67±253.26
	12.00	26.59±1.04	72.69±7.42	1498.70±508.17
	16.00	25.59±1.22	75.93±7.37	754.87±449.84
July	08.00	23.03±1.18	79.33±7.58	1110.39±506.23
	12.00	27.50±1.55	65.41±8.01	2529.90±1230.89
	16.00	25.68±1.26	70.36±7.83	1477.06±641.80

Table 5. Soil characteristics (physical and chemical properties) in eight parameters were tested from the soil at termite nests, 50 cm, and 100 cm away from the basal area of the nest

Nest code	Average moisture content (%)	Average soil acidity (pH)	Average C-organic (%)	Average total nitrogen (%)	Average C/N ratio	Average organic matter (%)	Texture of 3 faction (%)			Soil criteria
							Sand	Silt	Clay	
Nest 2-center	2.90	6.52[a]	3.14	0.3	10.47	5.41	30	27	43	Clay
Nest 2-50 cm	2.60	6.26[b]	2.67	0.24	11.13	4.60	27	27	46	Clay
Nest 2-100 cm	2.80	5.27[b]	1.76	0.17	10.35	3.03	29	27	44	Clay
Nest 4-center	2.50	7.39[a]	1.59	0.18	8.83	2.74	24	20	56	Clay
Nest 4-50 cm	2.30	7.31[a]	0.88	0.09	9.78	1.52	13	32	55	Clay
Nest 4-100 cm	2.30	7.30[a]	1.14	0.14	8.14	1.96	26	21	53	Clay
Nest 7-center	1.20	7.35[a]	2.14	0.24	8.92	3.69	32	42	26	Loam
Nest 7-50 cm	0.70	6.03[b]	1.65	0.18	9.17	2.84	32	39	29	Clay loam
Nest 7-100 cm	1.30	6.33[b]	2.13	0.23	9.26	3.67	33	40	27	Clay loam
Nest 8-center	2.60	6.63[a]	3.54	0.23	15.39	6.10	34	31	35	Clay loam
Nest 8-50 cm	2.90	3.25[c]	1.69	0.21	8.05	2.91	12	20	68	Clay
Nest 8-100 cm	2.10	6.25[b]	3.39	0.31	10.94	5.84	25	33	42	Clay

Note: Soil acidity: a: Neutral, b: Slightly acid, c: Acid

Moisture content

Soil moisture content values in nests with clay textures were higher than in the surrounding soil at a distance of 50 cm and 100 cm, while the loam and clay loam soil textures showed lower values in the nests than in the surrounding soil. The relationship between C-organic, organic matter, and clay to nest moisture content was investigated using a correlation test to identify the primary factors or causes affecting moisture content (Figure 5). The correlation test results showed that the correlation coefficient between moisture content and clay was strong (r: 0.720, *p*: 8.221804e-03), indicating a significant relationship. In contrast, the correlations between nest moisture content and C-organic and organic matter were weak and statistically non-significant (r: 0.167, *p*: 6.049763e-01; r: 0.166, *p*: 6.052321e-01, respectively). This result suggests that the clay primarily influences the moisture content of the nest. This data is reinforced by data on Nest 7, which has a low clay content (26-29%) and a moisture content ranging from 0.7% to 1.3%. In contrast, Nest 8-50 cm has a clay content of 68%, with a moisture content of 2.9%, which is higher than the center of the nest (Nest 8-center), which has a moisture content of 2.6% with a clay content of 35%. Clay has a tiny particle size (<0.002 mm) and a large surface area, with a high capacity to bind and hold water because water is trapped in these small pores and is difficult to move or flow out (Brady and Weil 2016).

The scatter plots (Figure 5) show positive correlations among C-organic, total nitrogen, and organic matter, while pH exhibits weak or negative relationships with these variables. This suggests that higher organic matter improves soil nutrient conditions around termite mounds. Pearson's correlation analysis supported these patterns and helped identify potential multicollinearity. Although some correlation coefficients (e.g., r: 0.720; r: -0.817) appeared relatively strong, these values must be interpreted cautiously because they were based on a limited number of observations, resulting in low statistical power. The results indicate general directional relationships rather than significant causal interactions.

Soil acidity

Data from the observation of soil acidity parameters showed that the pH value in the termite nest was higher than that of the soil at a distance of 50 cm and 100 cm from the nest. The degree of acidity (pH) of the soil in termite nests tends to be neutral (6.63-7.39) compared to the soil around the nest, which is slightly acidic to neutral (<6.5). Worker caste termites can increase the content of cations and saturated cations in soil materials in nest buildings (Subekti and Milanio 2023). The soil's acidity (pH) value is also influenced by the content of organic matter contained in termite nests, where the excretion of termite metabolic products, including nitrogen and carbonate compounds, can increase the soil's pH value.

C-organic, total nitrogen, and organic matter

According to White (2006), C-organic is a key indicator of soil fertility and structure, with values that correlate with soil quality. The higher the C-organic content, the better the quality of the mineral soil and the increased availability of soil nutrients. Organic matter in the termite nests is greater than that in the surrounding soil. This condition is common because termite nest formation involves the use of saliva and feces formed from the incomplete digestion of plant tissue. In addition, C-organic content is also influenced by termite activity, as these organisms decompose litter and other organic materials produced by plants (Priandhika et al. 2023). The higher organic matter content is found closer to the queen chamber as the core of the nest (Lee and Wood 1971). However, the overall C-organic content was low, with the highest value being only 3.54%. This data aligns with study conducted by Moata and Takalapeta (2021) that reported C-organic in agroforestry on Timor Island was <1-2%. Arinana et al. (2023) reported that C-organic levels in soil with termite activity ranged from 5.44% to 9.55%.

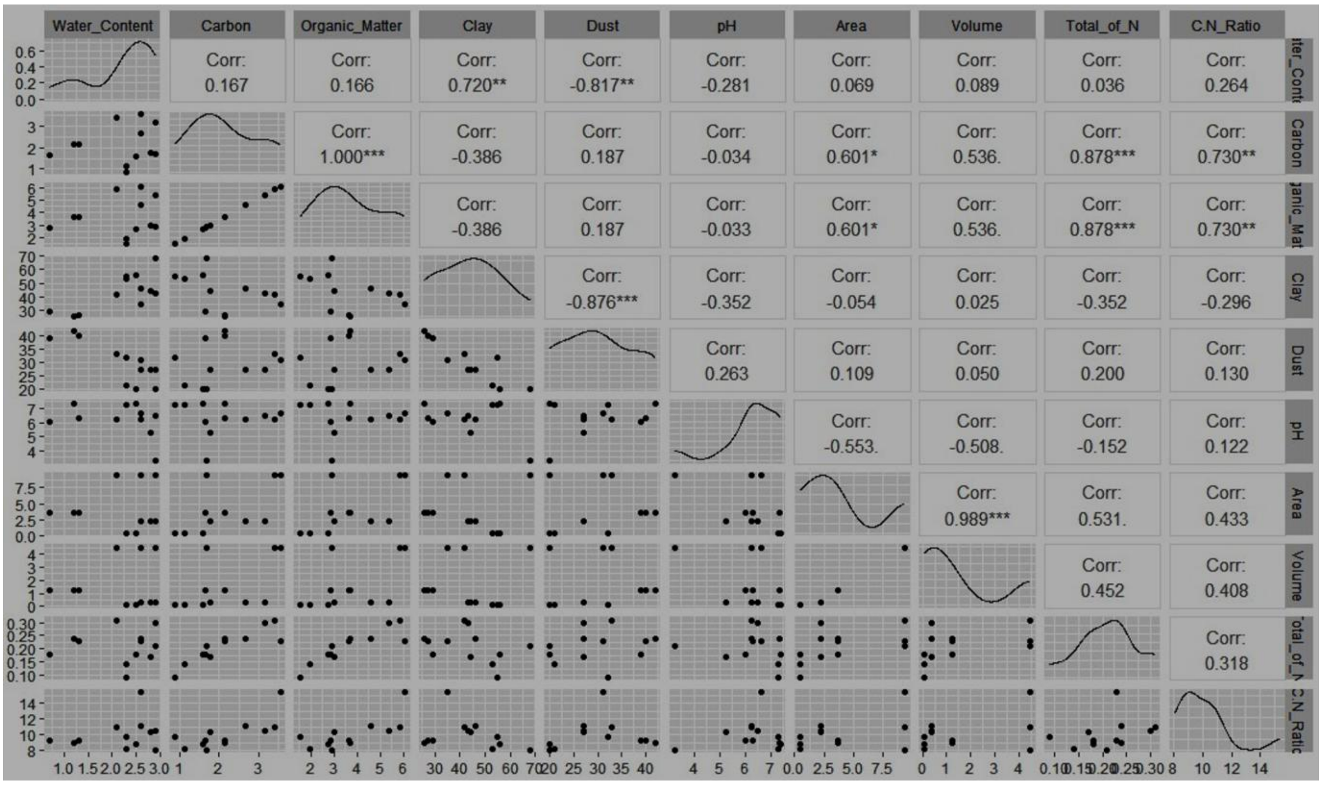

Figure 5. Correlation test was performed using correlation coefficient matrix for each chemical properties of the nest

Nitrogen levels are directly proportional to the amount of organic matter in the soil, but not as much as C-organic. The highest total nitrogen levels were found in termite nests, the center of subterranean termite activity. However, at some points, the total nitrogen level did not differ much from the soil at a distance of 100 cm from the termite nest. The higher C and N contents in the nest than in the soil around the nest are due to the subterranean termites building nests with the main ingredients of soil, plant residues (cellulose), and saliva. The saliva of *M. gilvus* contains the enzyme amylase (Subekti and Milanio 2023), a protein that has catalytic activity toward organic matter. Lee and Wood (1971) mentioned that plant tissues, humus, feces, and other organic matter contain little nitrogen, while the highest nitrogen levels are obtained from the digestion of fungi that grow on termite food. There is also a nitrogen rotation system maintained by termites, which utilizes the cannibal behavior of termites, which feed on dead, injured, and excess caste members.

Correlation between soil parameters and termite ecology

Analysis of the limited nest samples showed no significant differences ($p>0.05$) in soil acidity, C-organic, organic matter, total nitrogen, C/N ratio, silt, or clay content among the nests. The low levels of soil moisture, C-organic, organic matter, and total nitrogen are likely linked to the limited availability of organic inputs, such as plant biomass and litter, within the Mamar area and nearby agricultural land. Organic matter availability is influenced by the types and abundance of vegetation on the Mamar, which mainly consists of grasses, shrubs, and trees. As shown in Table 1, only a few plant species were present at the nest sites, consistent with Widiyono's (2008) findings that tree species richness and density in West Timor are generally low. The scarcity of plant species corresponds with the nest surface conditions, which are covered by only 3-18% litter and vegetation.

Multinomial regression of plant category data (grasses, shrubs, trees) against nest moisture, pH, C-organic, organic matter, and total nitrogen showed significant effects ($p\leq0.05$) for Nests 4 and 7, where the variables crossed the significance threshold. Nests 2 and 8 showed no significant effects (Figure 6). These patterns reflect differences in vegetation: Nests 4 and 7 contained eight plant species, mostly trees, whereas Nests 2 and 8 had fewer species. Variation in plant type and abundance influences canopy cover, ground cover, and litter production, which affect organic matter inputs to the soil. Plant diversity also alters microclimatic conditions (Njurumana 2009) that regulate termite activity and decomposition, thereby enhancing soil nutrient availability. Thus, greater plant abundance in Mamar areas stimulates termite activity and can improve soil quality, partly because species like *M. gilvus* rely on plant material to build fungus combs. Future studies could include seasonal monitoring to assess how termite activity and soil properties change between wet and dry periods.

The study area's dry climate and low rainfall are likely the primary factors contributing to the low moisture content and poor chemical properties of termite nests compared to other regions in Indonesia. These conditions also restrict plant growth, as vegetation adapts by shedding leaves, producing less biomass due to limited water availability, experiencing reduced photosynthesis, and generating thin leaf litter that dries quickly. According to Zulkaidah et al. (2021), the loss of vegetation types caused by land-use change in Sulawesi's tropical agroforestry systems greatly reduces organic matter input. The accumulation of organic matter from diverse tropical vegetation, along with climate, litter composition, and decomposer activity, is a major factor influencing litter decomposition (Oliveira et al. 2019). When vegetation is sparse or dominated by a single plant type, the input of organic material and the recycling of nutrients from plant litter are significantly reduced.

The multinomial regression model converged for nests 2, 4, 7, and 8, yielding a very low McFadden's pseudo-R^2 (2.37×10^{-10}) and AIC: 20.71, indicating a weak explanatory power. Among the predictors, C-organic and total nitrogen showed positive coefficients toward tree-dominated vegetation categories, but their effects were not statistically meaningful due to the limited sample size ($p>0.05$). Therefore, these results should be considered exploratory and descriptive rather than inferential.

Based on the multinomial regression output (Table 6), predictors in vegetation Category 3 (trees) showed significant effects on soil characteristics with $p<0.05$, while Category 2 (shrubs) did not. Positive β and Odds Ratios greater than 1 indicate that tree-dominated vegetation increases the probability of higher soil chemical values, particularly for organic carbon and total nitrogen. This pattern suggests that termite mounds associated with tree vegetation exhibit better nutrient conditions compared to those dominated by grasses or shrubs.

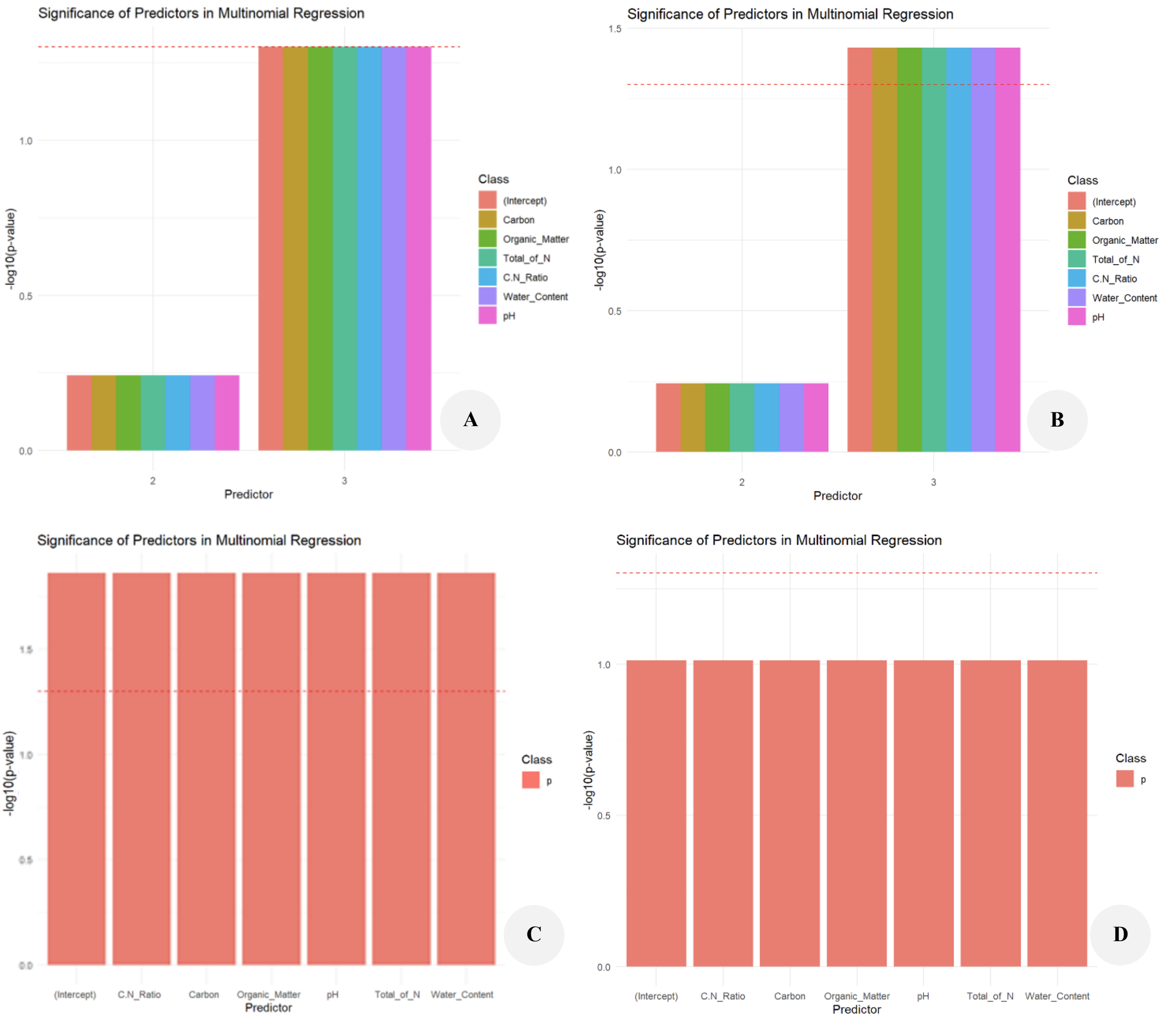

Figure 6. Graph of the results of multinomial regression analysis of plant species data (grass, shrubs, and trees) based on parameters of soil characteristics on Nests. A: 2, B: 4, C: 7, D: 8

Table 6. %HYY regression output

No	Predictor	Estimate	SE	Odds Ratio	p-value	Significance
1	2	0.00345	0.00610	1.003	0.5714	-
2	3	0.01036	0.00528	1.010	0.0499	*
3	2	0.01084	0.01916	1.010	0.5714	-
4	3	0.03252	0.01659	1.033	0.0499	*
5	2	0.01868	0.03300	1.018	0.5714	-
6	3	0.05604	0.02858	1.058	0.0499	*
7	2	0.00104	0.00183	1.001	0.5714	-
8	3	0.00311	0.00158	1.003	0.0499	*
9	2	0.03615	0.06387	1.037	0.5714	-
10	3	0.10845	0.05532	1.115	0.0499	*
11	2	0.01001	0.01769	1.010	0.5714	-
12	3	0.03004	0.01532	1.030	0.0499	*
13	2	0.02251	0.03978	1.023	0.5714	-
14	3	0.06753	0.03445	1.070	0.0499	*

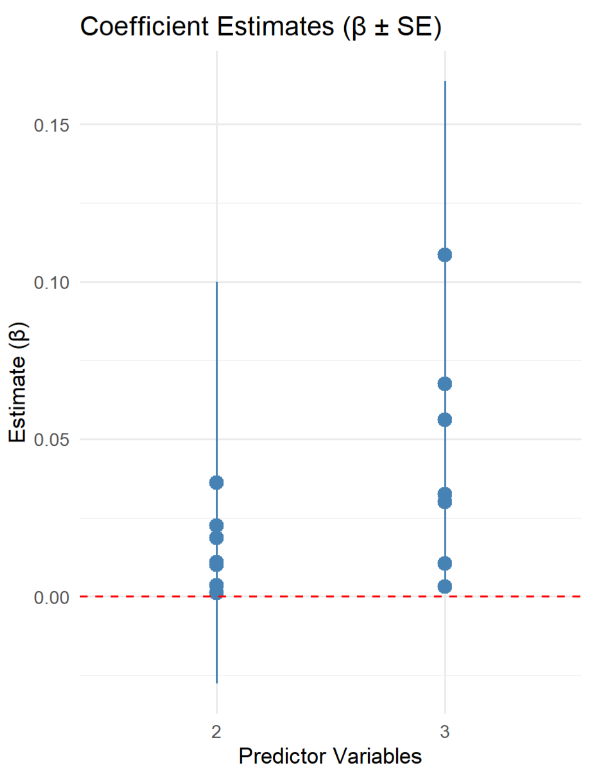

Figure 7. Graph of coefficient estimates and standard error

Figure 7 show that coefficient estimates (β±SE) from the multinomial regression model. Most β values were close to zero, and the confidence ranges overlapped the zero line, indicating that none of the soil parameters significantly affected vegetation category probabilities. The wide standard errors reflect high uncertainty caused by small sample size and limited variation in predictor variables.

In summary, two subterranean termite species, *M. gilvus* and *N. matangensis* (family Termitidae), were successfully identified, representing the first confirmed records of subterranean termites in Timor's traditional semiarid agroforestry system. Environmental measurements showed temperatures of 23.03-28.65°C, humidity of 65.41-84.87%, and light intensities of 594.19-2529.9 lux. Although humidity was often below the optimal range, these conditions still supported termite survival and nest development. As decomposers and soil engineers, both species contribute to improving the organic matter content and overall soil chemistry of the Mamar's inceptisols. Higher plant abundance further supports termite activity, particularly *M. gilvus*, which relies on plant material to build fungus combs. Conversely, the region's dry climate, low rainfall, and deciduous monsoon forest conditions have driven termites to adapt to low soil moisture, even inside their nests. This study highlights several future research opportunities, including seasonal monitoring, multi-site comparisons, standardized nest-density assessments, evaluation of termite nests as organic fertilizer sources, and testing local plants as natural termite repellents. The findings presented here are preliminary and limited by the small sample size. Further studies with larger replicated datasets and model validation (e.g., confidence intervals and residual diagnostics) are required to confirm the statistical relationships observed in this study. Also using standardized methods, such as transect sampling or trap-based density surveys, is recommended to strengthen and expand these findings.

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